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Cratech, Inc. is progressing on a 3-phase plan to develop a one ton per hour (tph) biomass-fueled integrated-gasifier gas turbine (BIGGT) power plant. The goal is to develop economical, small scale (1-20 MWe) power plants for entities worldwide that desire to use a variety of biomass resources for fuel including those with high ash content and prone to slagging. Phase 1 has been successfully completed. Phase I included design, fabrication and operation of a 0.5 tph air-blown pressurized fluidized bed gasification unit complete with a hot gas cleanup system. The unit was fueled with cotton gin trash (CGT), a biomass resource that is high in ash and very prone to slagging. The system demonstrated production of a gas from CGT that can be maintained at a minimum chemical heating value of 130 BTU/SCF, at an outlet temperature of 1265 +/- 15°F with a maximum particle content of 6.4 ppmw of 2.8 um maximum particle size.

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DEVELOPMENT OF A SMALL SCALE BIGGT POWER PLANT

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ABSTRACT

Cratech, Inc. is progressing on a 3-phase plan to develop a one ton per hour (tph) biomass-fueled integrated-gasifier gas turbine (BIGGT) power plant. The goal is to develop economical, small scale (1-20 MWe) power plants for entities worldwide that desire to use a variety of biomass resources for fuel including those with high ash content and prone to slagging. Phase 1 has been successfully completed. Phase 1 included design, fabrication and operation of a 0.5 tph air-blown pressurized fluidized bed gasification unit complete with a hot gas cleanup system. The unit was fueled with cotton gin trash (CGT), a biomass resource that is high in ash and very prone to slagging. The system demonstrated production of a gas from CGT that can be maintained at a minimum chemical heating value of 130 BTU/SCF, at an outlet temperature of 1265 +/- 15°F with a maximum particle content of 6.4 ppmw of 2.8 um maximum particle size. Funding assistance for this work was provided by the Western Regional Biomass Energy Program.

INTRODUCTION

The most economically promising path for supplying electrical and thermal power to entities that produce low value biomass product streams or that have a nearby source of low cost biomass is a properly designed and sized BIGGT.

This type of power plant has several benefits to industry and society. Among these are:

- A clean, renewable and efficient source of power.
- Power production that is continuous and carbon dioxide neutral.
- Power production for entities scarce in fossil fuels but abundant in biomass.
- Volume reduction of undesirable waste streams.
- Utilization of biomass that is high in ash and/or prone to slagging.
- Production of a useful ash byproduct.
- Emissions of particulates and nitrogen oxides can be very low.
- Power production with negligible sulfur dioxide emissions.

Large scale BIGGT power plants have technical challenges to meet. A small scale (1-20 MWe) BIGGT will also face these challenges. However, there are several additional challenges to meet before a small scale BIGGT can realize these benefits in a commercial environment. Some of these major technical challenges are:

- Capability to use a large variety of biomass fuels without extensive preprocessing.
- Carrying these fuels across a pressure barrier.
- Precise metering of minimally preprocessed biomass fuel.
- Minimal or no heat exchangers for gas cooling.
- All gas cleaning processes must be dry and very simple.
- Capability for running fully unattended.
- Very long endurance (at least match turbine's normal time between overhauls).

Cratech is progressing with a 3-phase plan to meet these challenges and develop a 1 tph BIGGT. These phases are:

Phase 1: Feed rate of 0.5 tph at 2 atmospheres pressure including a slipstream flow hot gas cleanup system.

Phase 2: Feed rate of 1 tph at 10 atmospheres pressure including a slipstream flow hot gas cleanup system.

Phase 3: Feed rate of 1 tph at 10 atmospheres pressure including a full flow hot gas cleanup system fully integrated with a gas turbine engine.

Phase 1 of this development program is complete. This report briefly describes the Phase 1 system and the results achieved with it. Phase 2 is underway and will build on what has been learned from Phase 1.

GENERAL SYSTEM DESCRIPTION

The following is a brief description of the Cratech biomass gasification system. Some of the system's special features are given more attention in the next sections.

Referring to Figure 1, the biomass is loaded into the live-bottom bulk biomass feeder (1). The biomass is pneumatically conveyed through line (2) into the high pressure feed vessel (HPFV)(3A). A fan at (3B) drives this conveying system. When the HPFV is filled, the top two valves close and the HPFV is pressurized. When the pressure between the HPFV and the meter hopper (4) is equalized the discharge valve opens and the biomass in the HPFV is fed into the meter hopper. When the meter hopper is full, the discharge valve closes, the HPFV depressurizes and the top two valves open. The filling cycle is complete and begins anew.

The meter hopper feeds the biomass into the reactor vessel (5) at a set rate. Air from the air compressor (6) is also fed into the reactor vessel . The fuel and air combine at a maximum temperature of about 1400°F to form a fuel gas laden with ash particles. Most of the ash is separated from the gas stream by cyclones (7). The ash discharges into an ash cooler to reduce the ash temp to approximately 150°F. The ash is depressurized and carried to a storage hopper. The gas enters a receiver vessel (8). Most of the gas flows through the hot gas pressure regulator valve (10) and is burned at a flare (11). A gas slipstream flows from the receiver vessel into the high temperature gas filter (9). The gas is ultracleaned of remaining ash particles then flows through a small gas backpressure valve to a small flare (12).

SELECTED SUBSYSTEM FEATURES

High Pressure Feed Vessel (HPFV)

The HPFV is a horizontally mounted pressure vessel that is 41" inside diameter (ID) x 120" long. It is of standard ASME pressure vessel construction rated at 250 psi. Its purpose is to carry the biomass across the pressure barrier (i.e., it functions as a lockhopper). It has a useful volume of 70 cubic feet. The vessel will consistently hold and reliably feed approximately 500 lbs of CGT (12% moisture) per cycle (a cycle was described in the preceding section). The largest valve is a 10" knife gate valve rated at 150 psi. This valve is the discharge valve leading to the meter hopper from the HPFV. This design allows for small valves and long valve cycle times. For a 0.5 tph feed rate a valve cycle is 30 minutes and for a 1 tph unit the valve cycle will be 15 minutes. Besides feeding CGT (with moisture up to 25%), this feed design has been successfully tested using cottonseed hulls and grass clippings (feed tests only, the latter two have not been fed into the reactor vessel). It would follow that any biomass with characteristics similar to these could be used in this design. Rice hulls (similar to cottonseed hulls) and bagasse (similar to CGT) are good examples. Wood chips of proper size (0.25" x 1" x 1" max) would also work very well. This design has been very reliable and will be essentially unchanged for Phase 2.

Meter Hopper

The meter hopper is a vertical pressure vessel with a 41" ID rated at 250 psi. Its effective volume is approximately 40 cubic feet. It has a live bottom that meters fuel into the reactor vessel. It is under constant pressure determined by the pressure in the reactor vessel. It was intended that the volume of the meter vessel match the volume of the HPFV, but to provide for reliable (no bridging) feeding of the CGT, the vessel's effective volume had to be decreased. The live-bottom volumetric feeder in the meter hopper has been very reliable and allows the system to function without noticeable gas quality fluctuations. However, we feel that it lacks the feeding precision required for fueling a gas turbine engine. A different type of feed meter will be used for phase 2.

Reactor Vessel

The reactor vessel is the heart of the system. The reactor vessel is an air-blown fluidized bed with a 24" ID. It is not ASME pressure rated and operates up to 15 psig. Biomass is fed into the bottom center of the bed using a unique proprietary design. Although this system has operated at 2 atmospheres (15 psig) max, we have experienced the challenges associated with higher pressure operation. We feel this qualifies us to operate at the Phase 2 pressure level of 150 psig once we have redesigned our reactor vessel. The fluidized bed reactor is a stable, smooth performer. Figure 2 is a graph of four variables related to the gasification system's performance: reactor vessel pressure, mass air flow, reactor bed average temperature and biomass feed rate. Notice in particular how stable the temperature was. There were seven thermocouples measuring seven temperatures in the bed in various radial positions at three different levels. During a 24 hour run all temperatures were within +/- 35°F of each other for the entire run.

High Temperature Filter Vessel (HTFV)

The HTFV is rated at 250 psi and contains four sintered metal filters with a total of 8 square feet of filter area. The filters are designed to remove 100% of all particles of 2.8 um size and larger. A slipstream flow of gas from the receiver vessel was passed through the HTFV to test its effectiveness. Generally 40 ACFM of gas flowed through the HTFV during the 55.5 hours it was tested. Nitrogen was used as the blowback gas. Figure 3 is a graph of four variables related to the HTFV's performance: filter vessel flow, filter vessel temperature, filter vessel pressure and filter vessel differential pressure. The HTFV proved to be very effective. By using a modified EPA Method 5, particulate samples were collected from the gas downstream of the HTFV. Ten samples were collected and showed a particle concentration with a mean of 3.13 ppmw and a sample standard deviation of 1.74 ppmw. The largest concentration was 6.37 ppmw. These sample particle concentrations may be high because there was some noticeable tar condensation on the sample filters which would add to their weight. Also when attempting to use a Coulter counter to measure the size distribution of the particles that were collected on the sample filters, there were so few particles that no reliable measurement could be taken. If this gas were used as turbine fuel the resulting particle concentration in the expanding gas (not including particles that might be contained in the combustion air) would be approximately 1 ppmw maximum.

Control and Data Acquisition System

The process is entirely controlled with ABB Kent-Taylor Modcell 2000 industrial microprocessor controllers. Phase 1 required approximately 40 digital control functions and 5 PID loops. The operator interface was via a host personal computer (PC). Data were recorded onto the host PC's hardrive. The system software (Iconic's Genesis) allowed realtime on-screen data plotting and history replay of data. The software allows for very flexible programming using blocks (no ladder logic programming) and the system's in/out modules are easily rearranged. Figures 2 and 3 are examples of history data replay plots.

GENERAL SYSTEM PERFORMANCE SUMMARY

Performance Graphs:
Figure 2. Gasification system performance showing the final 6 hours of a 24 hour run.
Figure 3. Filter vessel performance showing 2 hours out of a 6 hour run.

Fuel Used For Tests:
CGT from stripper harvested cotton.
High heating value approximately 6800 BTU/lb, 14.4% ash, 10 % moisture on dry basis.
Fuel mass feed flow rates ranged from 10.2 lb/min to 18.2 lb/min .

Typical Produced Gas Characteristics:
Gas Composition in mole percent: H_2 10.5%, CO_2 15.4%, C_2H_4 1.0%, C_2H_6 0.3%, O_2 2.5%, N_2 50.4%, CH_4 3% , CO 17%. 135 BTU/SCF, MW 27.2 .

Particle concentration in gas: mean of 3.13 ppmw with sample standard deviation of 1.74 of max size 2.8 um.

Gas outlet temperature during 24 hour run was 1265 +/- 15^{o}F.

Ash Characteristics:
Percent carbon in ash: average 47.7%
Particle size & production:
cyclone bottom exit: average mass median diameter (MMD) was 8.4 um production at 18.9 % of total biomass fed.
cyclone gas exit: average MMD was 4.9 um production is estimated at 2 % of total biomass fed.

Ash Slagging
CGT is very prone to slagging in a very short time. We did experience this severe problem. However, we have learned how to program operation of the system so that slagging can be reliably prevented; otherwise, we could never have completed an uneventful 24 hour run.

ACKNOWLEDGEMENTS

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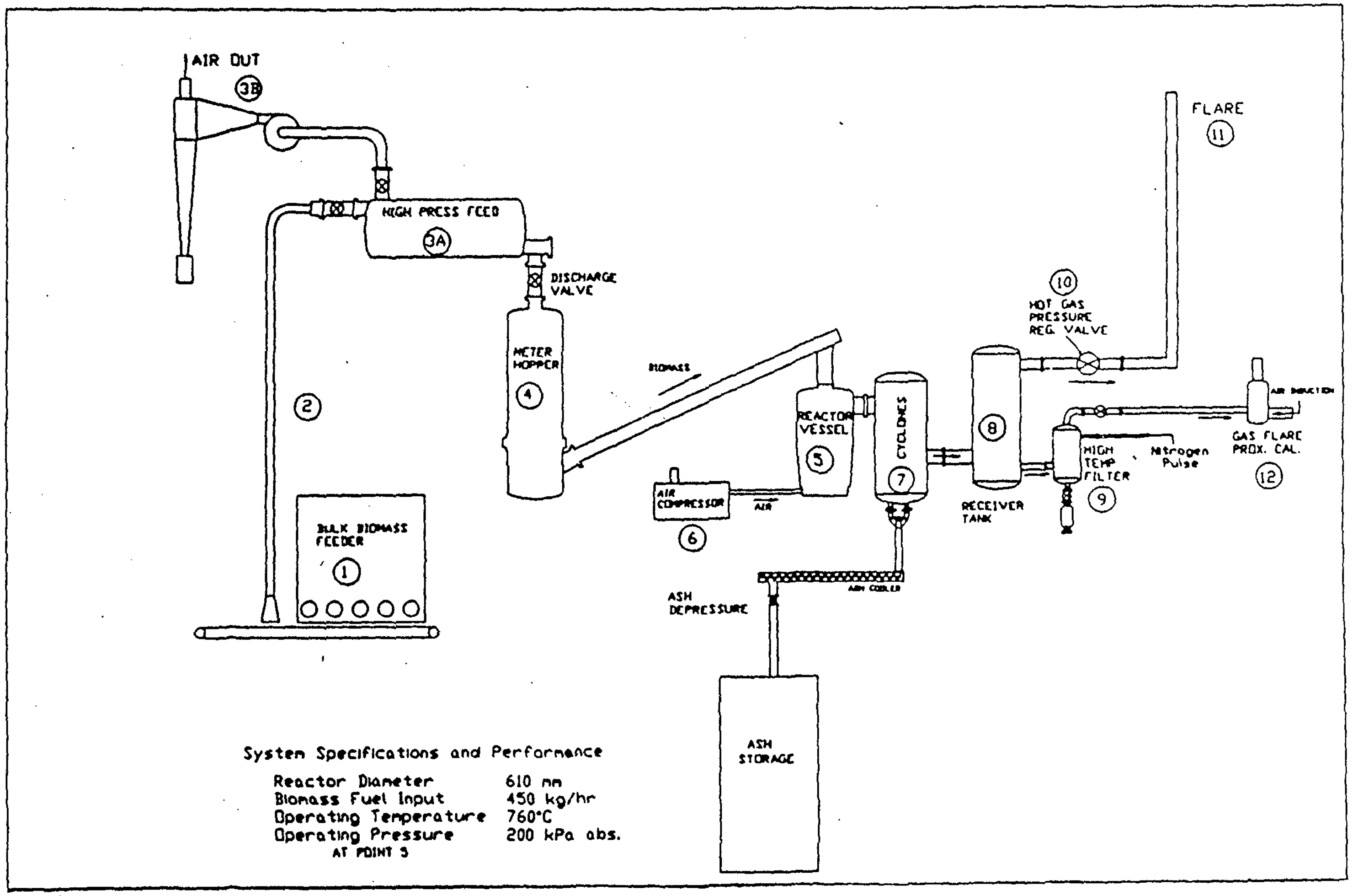

Figure 1. Cratech Pressurized Fluidized Bed Gasification System

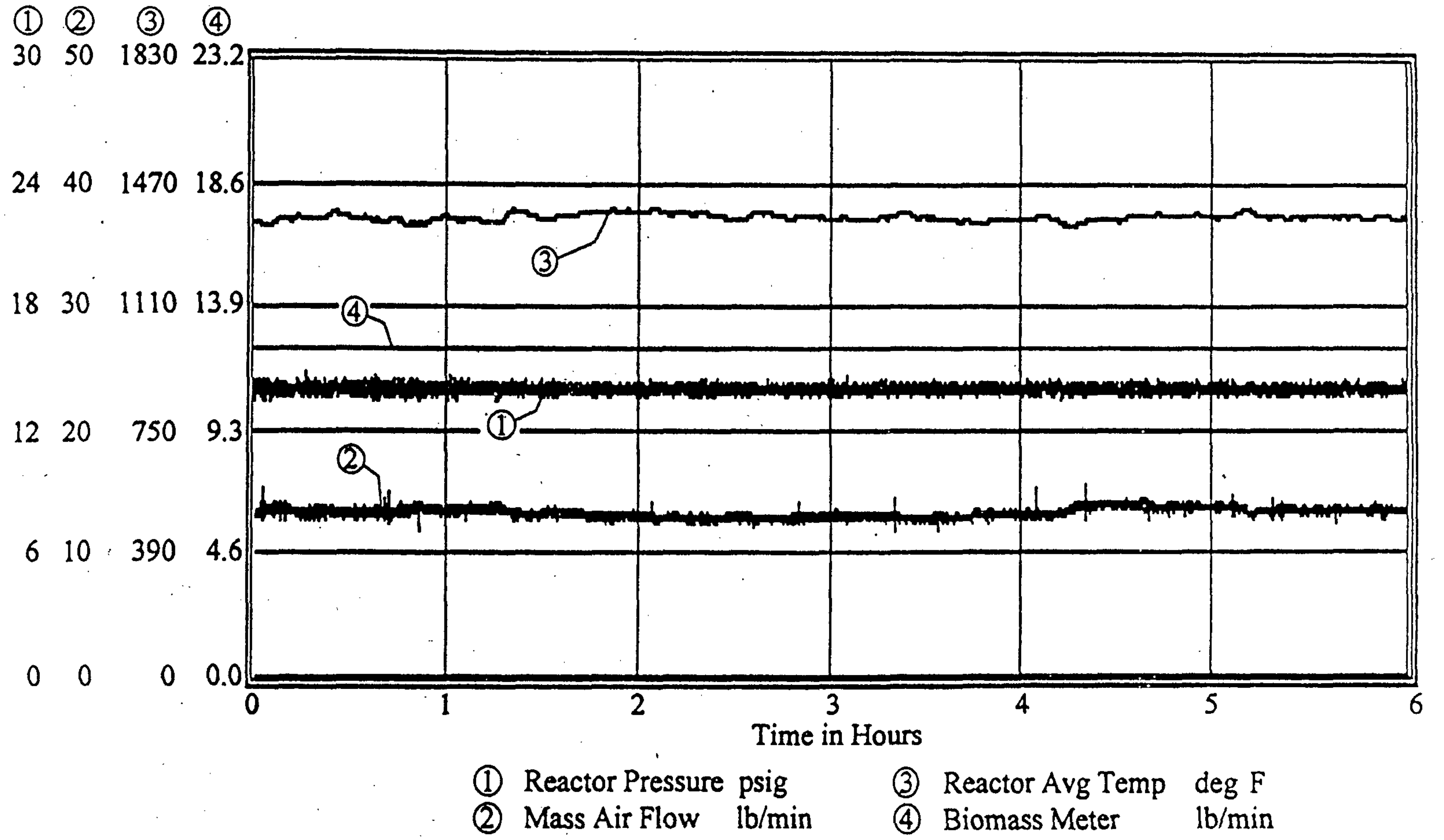

Figure 2. Gasification System Performance

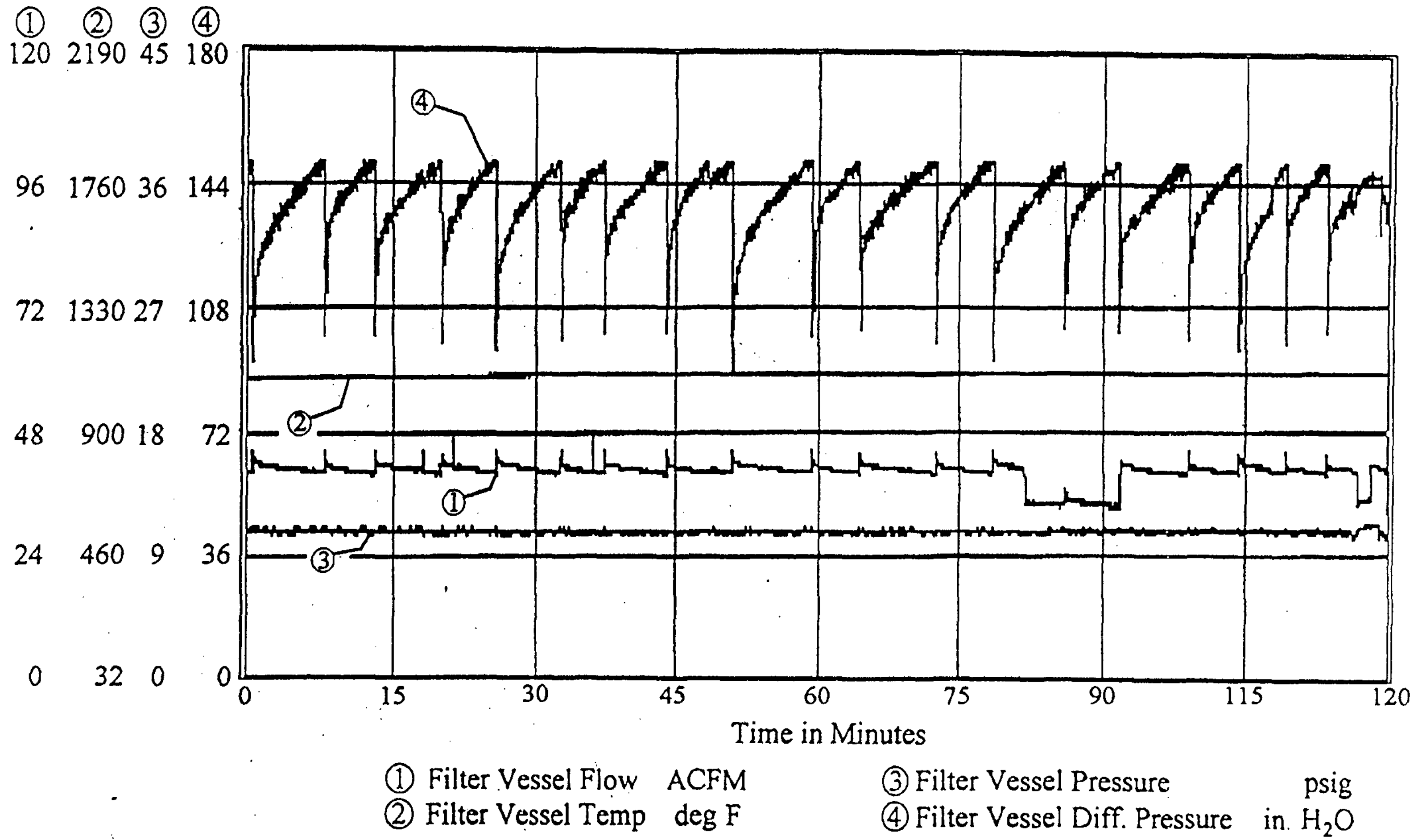

Figure 3. Filter Vessel Performance